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FULL LENGTH ARTICLE

The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study

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Abstract Physico-chemical parameters play a major role in determining the density, diversity and occurrence of phytoplankton in a headwater stream. The present study was conducted to assess the relationship between physico-chemical parameters and phytoplankton assemblages of Baldi stream of Garhwal Himalayas, India. Results showed an increased concentration in physico-chemical parameters (turbidity, total dissolved solids, nitrates and phosphates) has an adverse impact on the density of phytoplankton during monsoon season at the sampling site S_2, where maximum disturbances were recorded. Karl Pearson's correlation coefficient calculated between physico-chemical parameters and density of phytoplankton revealed that as sediment load increases in the stream, the growth of phytoplankton decreases. Canonical Correspondence Analysis (CCA) between environmental variables and dominant taxa of phytoplankton indicated the influence of physico-chemical parameters on phytoplankton distribution in freshwater ecosystem of Baldi stream of Garhwal Himalayas, India.

Introduction

Headwater streams are important freshwater ecosystems of the Himalayas. These freshwater ecosystems are nurseries of primary production due to high clarity of water. A minor change in physico-chemical parameters can influence the primary production (Sharma et al., 2007).

Phytoplankton are vital and important organisms which act as producer to the primary food supply in any aquatic ecosystem. They are the initial biological components from which the energy is transferred to higher organisms through food chain (Tiwari and Chauhan, 2006; Saifullah et al., 2014). The physico-chemical parameters are the major factors that control the dynamics and structure of the phytoplankton of aquatic ecosystem (Hulyal and Kaliwal, 2009). Changes in physico-chemical parameters of ecosystems have a substantial impact on the species that live within them. Seasonal variations in these parameters have an important role in the distribution, periodicity and quantitative and qualitative composition of freshwater biota.

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Several recent studies on physico-chemical parameters and phytoplankton community of rivers are conducted on the Greater Zab River, Iraq (Ali, 2010), River Haraz, Iran (Jafari et al., 2011), Imo River, Nigeria (Ogbuagu and Ayoade, 2012), River Thames, UK (Waylett et al., 2013), and Kenti River, Republic of Karelia (Chekryzheva, 2014). In North India, many recent studies have been conducted. These were focussed on the Chandrabhaga River (Sharma et al., 2007), Yamuna River (Chopra et al., 2012), Ganga River and its tributaries (Negi et al., 2012), Sutlej River (Sharma et al., 2013) and Jhelum River (Hafiz et al., 2014). However, no study has been conducted on physico-chemical parameters and phytoplankton composition of head water stream Baldi of Garhwal Himalayas. Therefore, the present study aims to determine the influence of physico-chemical parameters on phytoplankton composition of Baldi, the headwater stream ecosystem, which is prone to anthropogenic pressures.

Materials and methods

The head water stream Baldi is one of the important tributaries of the Song River flowing in Doon Valley of the Garhwal Himalayas. It lies in the coordinates of 30° 23′ N; 78° 08′ E in Raipur Block of Dehradun district of Uttarakhand state, India. The Baldi meets the Song River at Maldevta (Dehradun) after covering a distance of 14 km (Fig. 1). Three sampling sites on the Baldi stream were chosen on the basis of level of anthropogenic pressures. The upstream site S_1 (undisturbed site), the midstream site S_2 (highly disturbed site) and the downstream site S_3 (least disturbed site) were identified. Discharge of municipal waste water, use of soap and detergents for bathing and washing clothes, dumping of solid waste by tourists and locals were the common anthropogenic disturbances recorded at S_2, whereas only occasional washing of clothes was recorded at S_3. Monthly sampling was undertaken between 08:00 to 10:00 a.m. from the depth of 10 to 20 cm during November 2011–October 2012, representing three seasons (winter season = November–February; summer season = March–June; monsoon season = July–October). Five replicates of samples were obtained for each parameter and the results were integrated and recorded.

Water temperature, turbidity and pH were measured *in-situ* using the centigrade (0–110 °C) thermometer, Metzer Digital Turbidity Meter (Model-5D1M) and Toshcon Multiparameter Analyser, respectively. Dissolved oxygen, total dissolved solids (TDS), alkalinity, Calcium, Magnesium, hardness, nitrates, phosphates, Sodium and Potassium were analysed by using standard methods (Wetzel and Likens, 1991; APHA, 2005).

For phytoplankton analysis, one litre of sample water was collected and filtered through silk plankton net of mesh size 20 μm and was immediately preserved in opaque sample bottles containing 4% formalin solution for analyses by using the Sedgwick Rafter counting cell. Results were recorded in individuals per litre (ind. L^{-1}). Reimer (1962) method was followed to process the samples for light microscopy. The identification of phytoplankton was made with the help of Sarode and Kamat (1984), Ward and Whipple (1992), Munshi et al. (2010) and Bellinger and Sigee (2010).

The Karl Pearson's correlation coefficient was performed using Microsoft Excel 2007 to determine the relationship among the various physico-chemical attributes and different phytoplankton assemblages. Canonical Correspondence Analysis (CCA) was performed using Palaeontological STatistics (PAST) Software Version 3.06 to determine relationship between dominant phytoplankton taxa and physico-chemical parameters. Dominant phytoplankton species were selected on the basis of density (individuals L^{-1}). The species having more than 250 individuals L^{-1} annually were taken for analysis. The length of arrow is relative to the importance of the explanatory variable in the ordination, and arrow direction indicates positive and negative correlations (Jasprica et al., 2012; Laskar and Gupta, 2013).

Results and discussion

Monitoring the physico-chemical parameters is very important for studying the influence of these parameters on the distribution of various components of biodiversity in headwater stream (Sharma et al., 2007). Water quality is influenced by geological, hydrological, climatic and anthropogenic factors (Boon et al., 1992; Bartram and Balance, 1996). The physico-chemical parameters of water of Baldi stream have been presented in Table 1. Water temperature is considered as one of the important factors that controls aquatic life in a headwater stream (Wetzel, 1983). The lowest water temperature was recorded (10.95 °C) in winter season at S_1 and highest (15.03 °C) in summer season at S_3 in Baldi stream.

Maximum turbidity (52.58 NTU) was recorded at S_2 and minimum (40.49 NTU) at S_1 in the Baldi stream. Higher turbidity (95.23 NTU) was recorded at S_2 during in July–August (monsoon season) and a low turbidity (10.00 NTU) during January–February (winter season) in the Baldi stream. Similar findings were reported from the Chandrabhaga River in Garhwal Himalayas (Sharma et al., 2007) and Sutlej River of Himachal Pradesh (Jindal and Sharma, 2011). Maximum concentration (226.75 mg L^{-1}) of total dissolved solids was found in monsoon season at S_2 and minimum (45.00 mg L^{-1}) at S_1 the winter season.

Dissolved oxygen, is an important environmental parameter that decides ecological health of a stream and protects aquatic life (Chang, 2002). On annual average basis, maximum (8.56 mg L^{-1}) dissolved oxygen was recorded at S_1 and minimum (7.09 mg L^{-1}) at S_2. High dissolved oxygen was recorded during winter season at all the sites. It may be due to high photosynthetic rate of phytoplankton communities in clear water that results in higher values of dissolved oxygen (Sharma and Rathore, 2000; Ravindra et al., 2003). Higher dissolved oxygen in winter season and lower oxygen in monsoon were also recorded in Haraz River in Iran (Pejman et al., 2009), many rivers of Gangetic plain, India (Rani et al., 2011) and several rivers of the Central Himalayas including the Chandrabhaga River (Sharma et al., 2007) and the Tons River (Sharma et al., 2009).

The higher value (7.76) of pH was recorded at S_1 (Table 1) as, this site is rich in limestone rocks. The presence of limestone rocks results in higher pH (Ormerod et al., 1990). Alkaline water promotes high primary productivity (Kumar and Prabhahar, 2012). The water of Baldi stream was alkaline in nature throughout the study period. Alkaline nature of water was also reported in Greater Zab River, Iraq (Ali, 2010). Alkalinity (20–200 mg L^{-1}) is common in most of the fresh water ecosystems (Ishaq and Khan, 2013). Maximum alkalinity

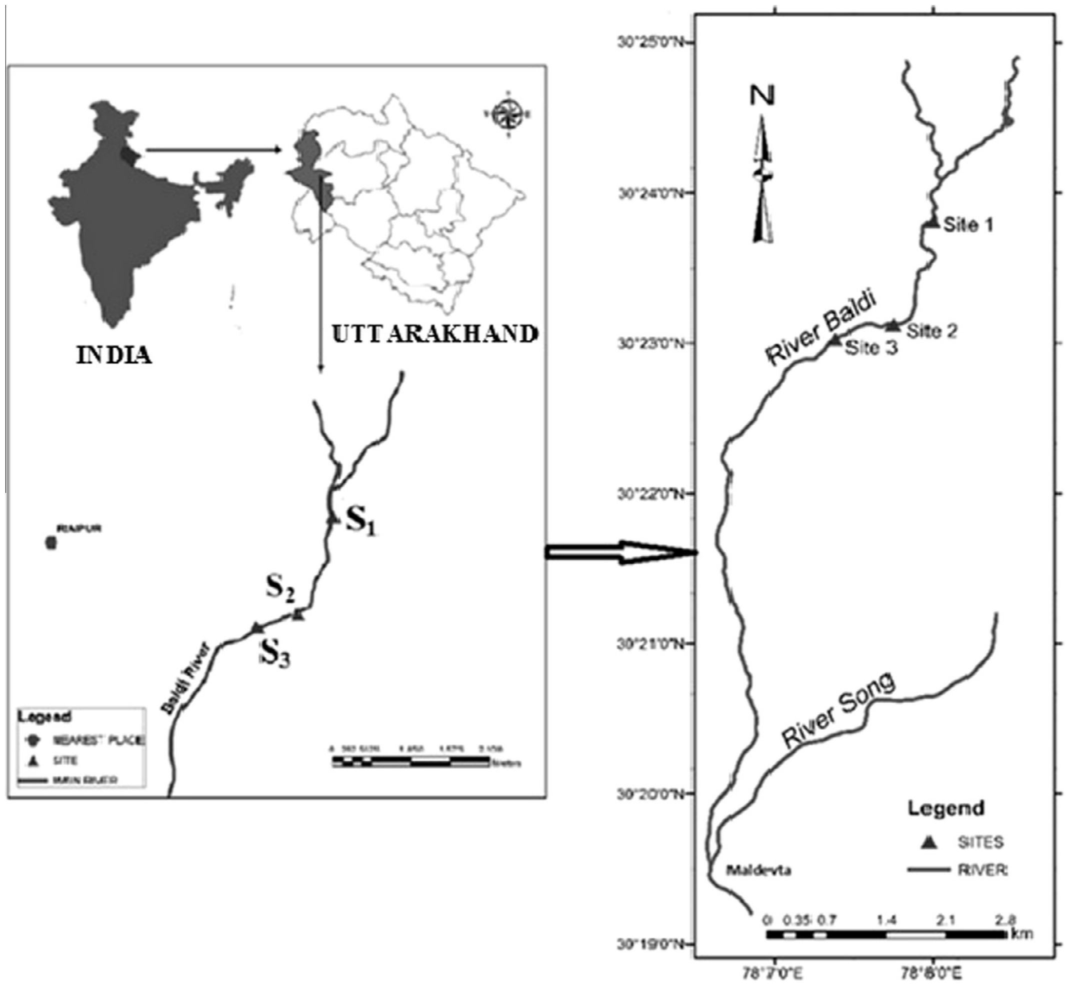

Figure 1 Location map showing selected study sites.

($67.64\ mg\ L^{-1}$) was reported at S_1 and minimum ($55.39\ mg\ L^{-1}$) at S_3 in Baldi stream. This may be due to the presence of high amount of carbonate rocks at S_1 as compared to S_2 and S_3. Natural water is mostly alkaline in nature due to the presence of carbonates in sufficient quantities (Todd, 1995).

Maximum ($165.33\ mg\ L^{-1}$) hardness was observed at S_1 and minimum ($150.56\ mg\ L^{-1}$) at S_3 (Table 1). The values of total hardness recorded in the Baldi stream were more than the prescribed standard ($100\ mg\ L^{-1}$) of World Health Organization (WHO). The high values of hardness recorded during winter season in the Baldi stream may be attributed to the increased mobilization of hardness causing elements like Calcium and Magnesium to be released from the subsurface ground waters having higher hardness (USEPA, 2000; Badrakh et al., 2008). Higher values of hardness were also reported in Haraz River, Iran (Jafari et al., 2011). The concentration of Calcium ranged from $68.33\ mg\ L^{-1}$ (S_1) to $60.35\ mg\ L^{-1}$ (S_3) in the Baldi stream. As compared to Calcium concentration, a low concentration of Magnesium was observed in Baldi stream. Similar findings were reported from the Haraz River, Iran (Jafari et al., 2011).

Maximum concentration ($0.090\ mg\ L^{-1}$) of nitrates was recorded at S_2 and minimum ($0.073\ mg\ L^{-1}$) at S_1 in Baldi stream (Table 1). It may due to maximum anthropogenic activities at S_2. High levels of nitrates showed the effect of high anthropogenic activities and agricultural runoffs (Kannel et al., 2007). Seasonally, maximum concentrations of nitrates were observed during monsoon, when headwater stream Baldi was flooded and received high amount of debris from the watershed. Maximum concentrations of Phosphates were recorded ($0.054\ mg\ L^{-1}$) in monsoon season and minimum ($0.026\ mg\ L^{-1}$) in winter season under the present study. Similar findings were reported from rivers Tons River (Sharma et al., 2009), Ghagra and Gandak Rivers (Rani et al., 2011) and Rapti River (Kushwaha and Agrahari, 2014). The presence of high concentrations of phosphates in Baldi stream at S_2 may be due to maximum anthropogenic activities at this site.

No specific variation was recorded in the concentration of Potassium at all three sites in head water stream Baldi (Table 1). Maximum ($10.36\ mg\ L^{-1}$) concentration of Sodium was recorded at S_2 and minimum ($9.50\ mg\ L^{-1}$) at S_1 (Table 1). Weathering of rocks is very common in lower stretches of upper Ganges which results in addition of Sodium and Potassium in aquatic bodies (Sharma, 2014). Thus, the overall trend of physico-chemical parameters in the study area revealed that the sampling site S_2 is most degraded while, the better water quality persists at S_1.

Table 1 Mean seasonal and annual mean (based on monthly variation) of physico-chemical attributes in headwater stream Baldi from November 2011 to October 2012.

Season		Winter		Summer		Monsoon		Annual mean	
Parameters	Sites	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Water temperature (°C)	S_1	10.95	1.30	14.63	0.842	14.50	1.47	13.36	2.10
	S_2	11.10	1.26	14.80	0.849	14.73	1.44	13.54	2.11
	S_3	11.33	1.26	15.03	0.974	15.00	1.50	13.78	2.15
Turbidity (NTU)	S_1	10.00	10.46	33.55	18.54	77.93	20.096	40.49	33.15
	S_2	17.00	11.49	45.20	20.67	95.23	17.560	52.48	37.12
	S_3	12.75	11.41	38.90	19.99	84.08	18.246	45.24	34.38
TDS (mg L^{-1})	S_1	45.00	13.52	81.38	41.39	192.75	46.764	106.38	73.64
	S_2	63.75	14.10	106.98	53.50	226.75	44.709	132.49	81.03
	S_3	55.00	15.81	96.40	48.54	205.75	43.177	119.05	75.04
pH	S_1	7.69	0.03	7.77	0.05	7.83	0.053	7.76	0.07
	S_2	7.63	0.05	7.70	0.05	7.75	0.085	7.69	0.08
	S_3	7.66	0.04	7.73	0.05	7.79	0.064	7.73	0.07
Dissolved oxygen (mg L^{-1})	S_1	9.83	0.48	8.48	0.98	7.37	0.867	8.56	1.28
	S_2	8.02	0.42	7.15	0.61	6.12	0.808	7.09	1.00
	S_3	8.84	0.30	7.72	0.71	6.80	0.769	7.79	1.04
Alkalinity (mg L^{-1})	S_1	51.23	11.51	67.18	16.65	84.53	10.536	67.64	18.54
	S_2	46.08	7.75	61.75	15.63	72.75	12.539	60.19	16.02
	S_3	42.05	8.39	56.10	13.49	68.03	13.610	55.39	15.56
Calcium (mg L^{-1})	S_1	76.5	8.06	66	10.33	50.5	8.7	68.33	13.85
	S_2	72.25	6.95	62	9.93	45.5	9.68	64.92	14.07
	S_3	64.50	9.54	57.50	7.59	41.50	8.103	60.35	12.63
Hardness (mg L^{-1})	S_1	171.25	10.31	151.25	12.31	110.5	16.82	165.33	29.06
	S_2	160.25	9.32	143.50	12.48	109.50	16.76	156.42	29.31
	S_3	157.25	16.92	140.75	12.04	104.25	18.118	150.56	28.86
Magnesium (mg L^{-1})	S_1	44.75	4.43	35.25	2.22	28	9.83	45.08	16.36
	S_2	40	4	31.5	5	24	8.45	38.56	16.36
	S_3	36.75	7.80	27.25	9.54	22.75	11.955	32.15	17.44
Nitrates (mg L^{-1})	S_1	0.060	0.00	0.076	0.01	0.083	0.013	0.073	0.013
	S_2	0.076	0.00	0.095	0.01	0.100	0.013	0.090	0.014
	S_3	0.066	0.00	0.084	0.01	0.087	0.013	0.079	0.013
Phosphates (mg L^{-1})	S_1	0.026	0.01	0.046	0.02	0.059	0.013	0.044	0.019
	S_2	0.040	0.01	0.054	0.02	0.068	0.012	0.054	0.017
	S_3	0.035	0.01	0.049	0.02	0.063	0.011	0.049	0.017
Sodium (mg L^{-1})	S_1	10.28	0.39	8.68	0.52	9.55	0.858	9.50	0.88
	S_2	10.64	0.52	10.60	0.07	9.85	0.342	10.36	0.50
	S_3	9.56	0.16	10.06	0.23	10.24	0.125	9.95	0.34
Potassium (mg L^{-1})	S_1	3.50	0.22	4.13	0.45	4.12	0.093	3.91	0.40
	S_2	3.69	0.36	3.86	0.41	4.40	0.137	3.98	0.43
	S_3	3.55	0.34	3.81	0.10	4.48	0.119	3.95	0.45

Phytoplankton community

Thirty-four species of phytoplankton were recorded in the Baldi stream represented by three major groups, Bacillariophyceae (20 species), Chlorophyceae (10 species) and Cyanophyceae (4 species). Maximum density (984 individuals L^{-1}) of phytoplankton was observed at S_1 and minimum (553 individuals L^{-1}) at S_2 (Fig. 2). Maximum density of phytoplankton was recorded during winter months (January–February) in Baldi stream. It starts declining from March onwards and attains lowest ebb during July–August (monsoon months). Again phytoplankton showed an increase in their density in post monsoon season and attains peak in winter season (Fig. 3). Sharma et al. (2007) also reported high density of phytoplankton during winter months in Chandrabhaga River, Garhwal Himalayas. The environmental health of a particular aquatic ecosystem depends upon spatial–temporal distribution, species composition, relative abundance and biomass of phytoplankton (Khattak et al., 2005). It was revealed from the present study that phytoplankton abundance showed the same trend between different sites while, phytoplankton compositions were different at all the three sites. This may be due to variations in water quality between different sites (Pattrick, 1977).

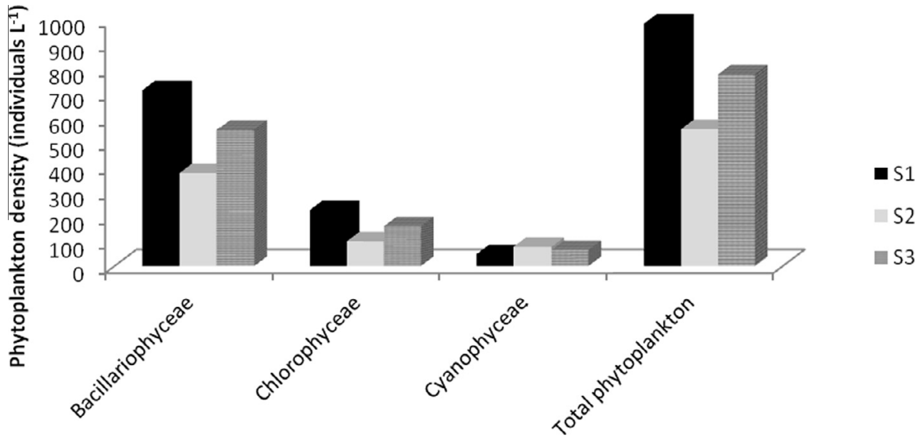

Figure 2 Major group and density of phytoplankton (annual mean) at different study sites.

Bacillariophyceae

Bacillariophyceae has been recorded as the most dominant group followed by Chlorophyceae and Cyanophyceae in the Baldi stream. It contributed 71% to the total phytoplankton population of Baldi stream while, Chlorophyceae and Cyanophyceae contributed 21% and 8%, respectively. Hafiz et al. (2014) also recorded Bacillariophyceae as the dominant group over other groups in the Jhelum River in Kashmir Himalayas. Bacillariophyceae was also recorded as the dominant group in the Imo River, Nigeria (Ogbuagu and Ayoade, 2012), Kenti River, Republic of Karelia (Chekryzheva, 2014) and Greater Zab River, Iraq (Ali, 2010). The study area of Baldi stream is rich in calcareous rocks which favour growth of Bacillariophyceae. Pearsall (1924) and Pattrick (1977) suggested that calcium carbonates–bicarbonates promote growth of Bacillariophyceae.

A total of 20 species of Bacillariophyceae were recorded from the Baldi stream. The dominant species were *Cymbella aequalis*, *Diatoma vulgaris*, *Fragilaria pinnata*, *Fragilaria arcus*, *Frustulia rhomboides*, *Gomphonema geminatum*, *Gomphonema longiceps*, *Navicula confervacea*, *Navicula radiosa*, *Nitzschia diversa*, *Nitzschia denticula*, *Pinnularia* sp., *Cocconeis* sp. and *Achnanthes affinis*. Density of Bacillariophyceae was found to be maximum (712 individuals L^{-1}) during winter months at S_1 and minimum (374 individuals L^{-1}) at S_2 during monsoon months (Fig. 2) calculated on annual mean basis. Similar findings were reported from the River Ganga and its tributaries in the Garhwal Himalayas (Negi et al., 2012) and Chandrabhaga River of Garhwal Himalayas (Sharma et al., 2007). This may due to maximum environmental degradation in Baldi stream during monsoon season and less turbid water enhances photosynthesis during winter season resulting in high growth. Due to their short regeneration time and sensitive behaviour towards ecological characteristics, Bacillariophyceae can be used as bio-indicators for water quality evaluation (Stevenson and Pan, 1999; Goma et al., 2005).

Chlorophyceae

The second most abundant group of phytoplankton recorded during the present study was Chlorophyceae. It contributes 21% of the total phytoplankton population. A total of 10 species of Chlorophyceae were recorded from the Baldi stream. *Cladophora glomerata*, *Hydrodictyon* sp., *Microspora amoena*, *Spirogyra* sp. and *Chlorococcum humicola* were found to be the dominant species. Maximum (224 individuals L^{-1}) density was recorded at S_1 followed by moderate (162 individuals L^{-1}) density at S_3 and minimum (101 individuals L^{-1}) at S_2 (Fig. 2). High density of Chlorophyceae was recorded during winter season (January–February) and low density during monsoon season (July–August) at all the three sites. It may be due to low water velocity, high dissolved oxygen and utilization of nutrients during winter season in Baldi stream. Tiwari and Chauhan (2006) also reported maximum abundance of Chlorophyceae during winter season in Kitham Lake, Agra, India.

Cyanophyceae

The Cyanophyceae contributes only 8% to the total phytoplankton population of Baldi stream. Maximum density (78 individuals L^{-1}) of Cyanophyceae was recorded at S_2 and minimum (48 individuals L^{-1}) at S_1 in Baldi stream (Fig. 2). A total of four species (*Anabaena ambigua*, *Nostoc* sp., *Phormidium* sp., *Oscillatoria tenuis*) were recorded. The distribution of Cyanophyceae depends upon nutrient (nitrates and phosphates) availability (Smith, 1983). Cyanophyceae was found as the dominant group at S_2, where highest concentrations of nitrates and phosphates were found as compared to S_1 and S_3 (Table 1). High turbidity and TDS favour growth of Cyanophyceae (Harsha and Malammanavar, 2004). The presence of high density of Cyanophyceae indicates high pollution load and nutrient rich condition (Muhammad et al., 2005; Tas and Gonulol, 2007).

Correlation between physico-chemical parameters and phytoplankton

Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) method was used to determine the relationships between phytoplankton and environmental variables. The arrow length indicates the importance of variable and shows positive or negative correlations with axis (Abrantes et al., 2006; Liu et al.,

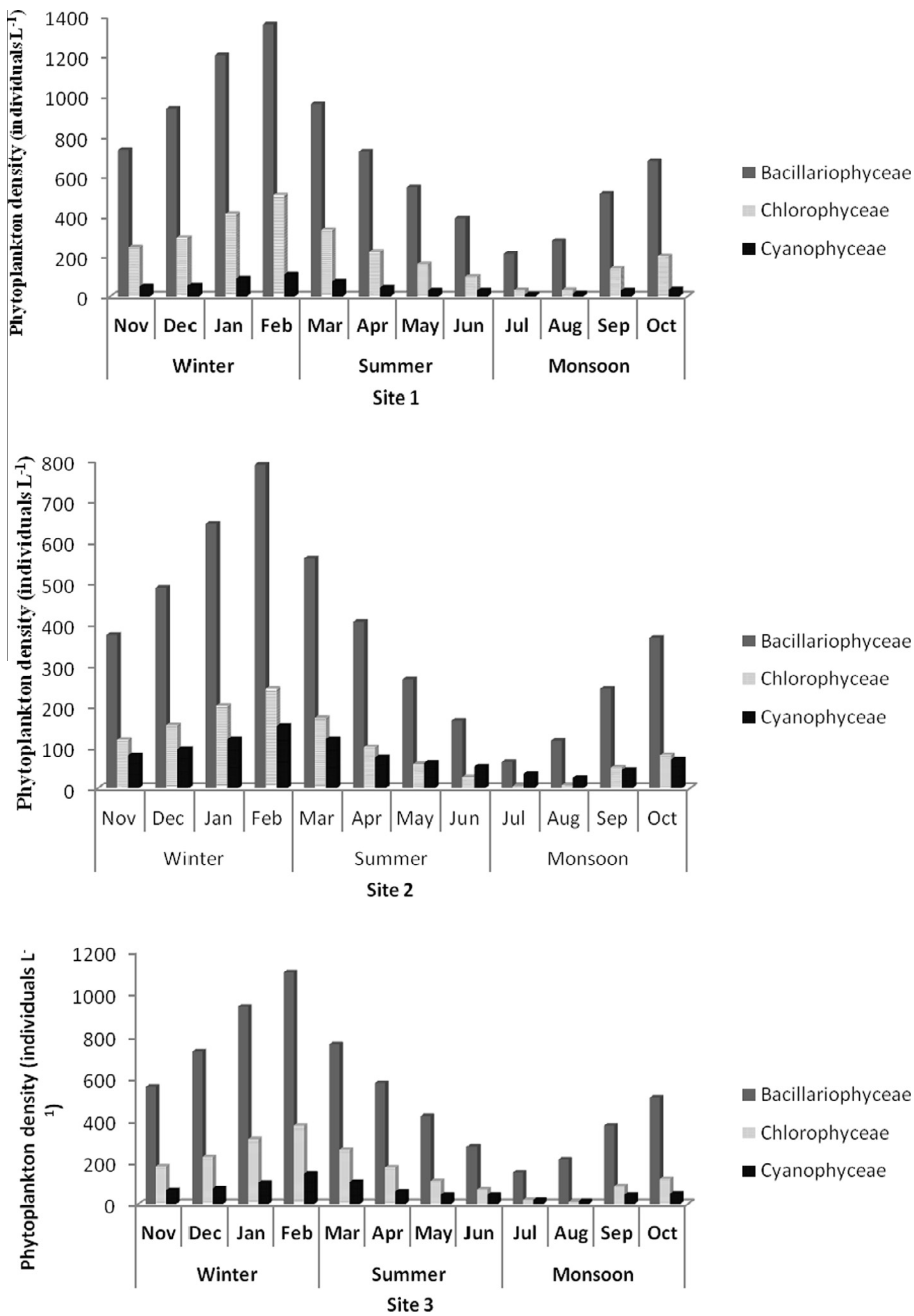

Figure 3 Monthly and seasonal distribution of phytoplankton at three study sites of head water stream Baldi from November 2011 to October 2012.

2010). Percentages of variance and Eigen values of each site in axis 1 were found to be higher than axis 2 (Table 2). Similar findings were reported by Liu et al. (2010).

At the sampling site S_1, CCA has been drawn between 13 physico-chemical parameters and 25 dominant species of phytoplankton (Fig. 4) Eigen value for axis 1 (0.020) explained 36.89% correlation and axis 2 (0.012) explained 22.36% correlation between physico-chemical parameters and dominant species of phytoplankton. Alkalinity, pH and dissolved oxygen indicate close relationship with phytoplankton community which shows high productivity at S_1. *Pinnularia* sp. and *D. vulgaris* were positively correlated with axis 1. *Pinnularia* sp., *Spirogyra* sp., *Tabellaria fenestris*, *Achnanthes lanceolata* and *Nodularia* sp. indicated positive correlation with alkalinity, dissolved oxygen and pH. However, *F. pinnata* and *Coconneis* sp. showed positive relationship with nitrates, water temperature and Potassium. The distribution of *Cyclotella* sp. was found to be least affected by these physico-chemical parameters.

At S_2, 13 physico-chemical parameters and 6 dominant species of phytoplankton were taken into consideration to draw CCA (Fig. 5). As, the sampling site S_2 was the most disturbed site only a few phytoplankton species were able to grow at this site. At axis 1, Eigen value (0.029) explained 70.12% and Eigen

Table 2 CCA biplot scores of physico-chemical parameters at three sites of headwater stream Baldi from November 2011 to October 2012.

		S_1		S_2		S_3	
		Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Water temperature	WT	0.680	−0.346	0.707	0.092	0.690	−0.291
Turbidity	Tu	0.944	0.184	0.684	0.496	0.909	0.054
TDS	TD	0.967	0.121	0.774	0.381	0.926	−0.091
pH		−0.722	0.148	−0.831	−0.160	0.925	0.015
Dissolved oxygen	DO	−0.932	0.096	−0.788	−0.289	−0.845	0.083
Alkalinity	Al	−0.896	0.083	−0.776	−0.051	−0.807	0.179
Calcium	Ca	−0.867	−0.154	−0.642	−0.475	−0.846	−0.119
Magnesium	Mg	−0.882	−0.124	−0.540	−0.689	−0.788	−0.308
Hardness	Ha	−0.897	−0.141	−0.601	−0.600	−0.838	−0.219
Nitrates	Ni	0.866	−0.411	0.945	−0.002	0.829	−0.475
Phosphates	Ph	0.632	0.077	0.710	0.042	0.063	−0.224
Sodium	Na	−0.524	0.718	−0.658	−0.391	0.786	−0.153
Potassium	K	0.514	−0.153	0.365	0.345	0.673	0.416
Eigen value		0.0201	0.0122	0.029	0.007	0.029	0.013
Percentage of variance		36.89	22.36	70.12	17.42	49.81	22.13

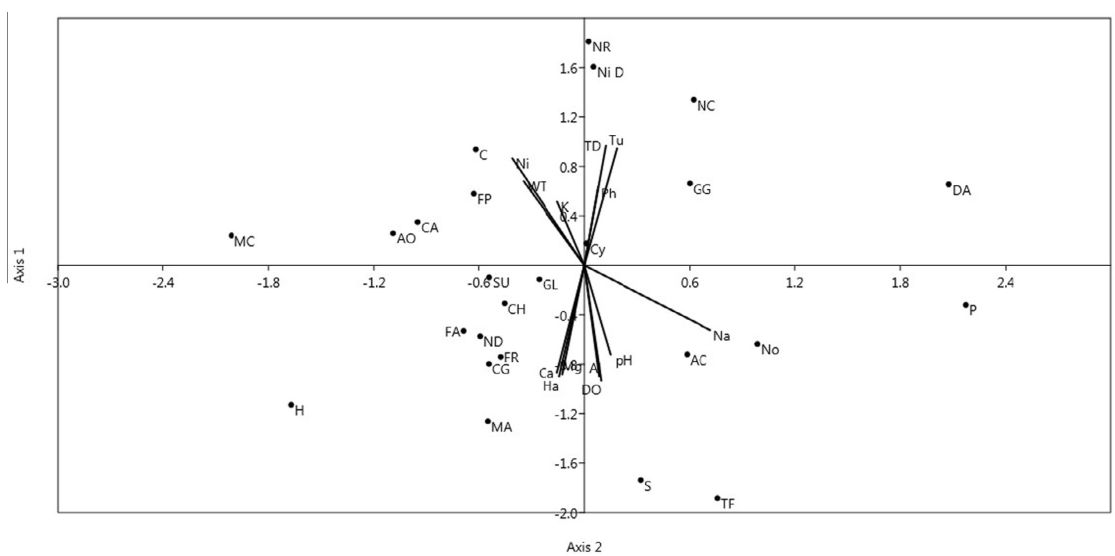

Figure 4 CCA biplot at site 1 between physico-chemical parameters and phytoplankton species (Dominant phytoplankton species: CA: *Cymbella aequalis*, DA: *Diatoma vulgaris*, FP: *Fragilaria pinnata*, FA: *Fragilaria arcus*, FR: *Frustulia rhomboides*, GG: *Gomphonema geminatum*, GL: *Gomphonema longiceps*, NC: *Navicula confervacea*, NR: *Navicula radiosa*, ND: *Nitzschia diversa*, NiD: *Nitzschia denticula*, P: *Pinnularia* sp., C: *Cocconeis* sp., AO: *Achnanthes affinis*, AC: *Achnanthes lanceolata*, No: *Nodularia* sp., Cy: *Cyclotella* sp., MC: *Meridion circulare*, TF: *Tabellaria fenestris*, SU: *Synedra ulna*, CG: *Cladophora glomerata*, H: *Hydrodictyon* sp., MA: *Microspora amoena*, S: *Spirogyra* sp., CH: *Chlorococcum humicola*).

value of axis 2 (0.007) explained 17.42% correlation between physico-chemical parameters and dominant phytoplankton species. *Pinnularia* sp. and *N. diversa* showed positive correlation with axis 1 which indicates the effect of Potassium, turbidity, TDS, nitrates, phosphates and water temperature on their distribution. The close relationship between pH, hardness and alkalinity showed the alkaline nature of water. It may be due to presence of calcareous nature of rocks present in the study area. *F. pinnata* distribution was affected by Calcium, Magnesium, Sodium and dissolved oxygen, as, it has strong relationship with these parameters. *F. pinnata* showed a different correlation with physico-chemical parameters at S_2 as compared to S_1. This may be due to maximum disturbances at S_2 which results in habitat destruction of this species. The presence of high density of *A. ambigua* and *Nostoc* sp. at S_2 indicated highly polluted nature of this site. These species have more tolerance power than other species and are known as pollution indicator (Kumari et al., 2008).

At S_3, CCA has been drawn between 13 physico-chemical parameters and 18 dominant phytoplankton species (Fig. 6). Eigen value of axis 1 (0.029) explained 49.81% relationship between environmental parameters and phytoplankton community. Whereas, Eigen value of axis 2 (0.013) explained 22.13% relationship. *Synedra ulna*, *A. lanceolata*, *Nodularia* sp., *T. fenestris* and *Pinnularia* sp. showed positive correlation with axis 1 and their distribution is affected by dissolved

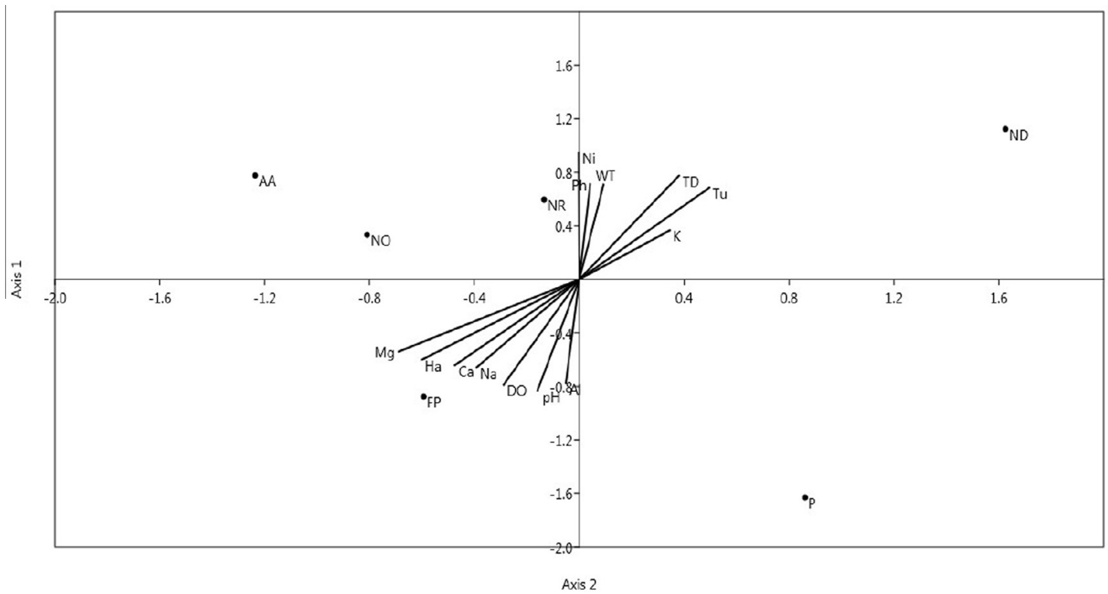

Figure 5 CCA biplot at site 2 between physico-chemical parameters and phytoplankton species (Dominant phytoplankton species: ND: *Nitzschia diversa*, FP: *Fragilaria pinnata*, NR: *Navicula radiosa*, P: *Pinnularia* sp., AA: *Anabaena ambigua*, No: *Nostoc* sp.).

oxygen and alkalinity. *F. pinnata* showed positive correlation with nitrates, Sodium and water temperature. The presence of *A. ambigua* at S_3 indicated some disturbance at this site. Magnesium, Calcium and hardness showed positive correlation with axis 2 which indicates an effect of ions in headwater stream. The correlation analysis was found almost similar at S_1 and S_3. This shows a recovery of water quality at S_3. From the CCA plots, it was revealed that distribution of phytoplankton community in headwater stream Baldi depends on the physico-chemical parameters.

Karl Pearson's correlation coefficient

Karl Pearson's correlation coefficients calculated between various physico-chemical attributes and density of phytoplankton dwelling the Baldi stream have been presented in Table 3. Water temperature has positive correlation ($r = 0.837$, $p < 0.05$) with pH. pH in water governs chemical and biological processes, whereas temperature in water governs the availability of oxygen (Kowalkowski et al., 2006). TDS has positive correlation with temperature ($r = 0.705$, $p < 0.05$) in the Baldi

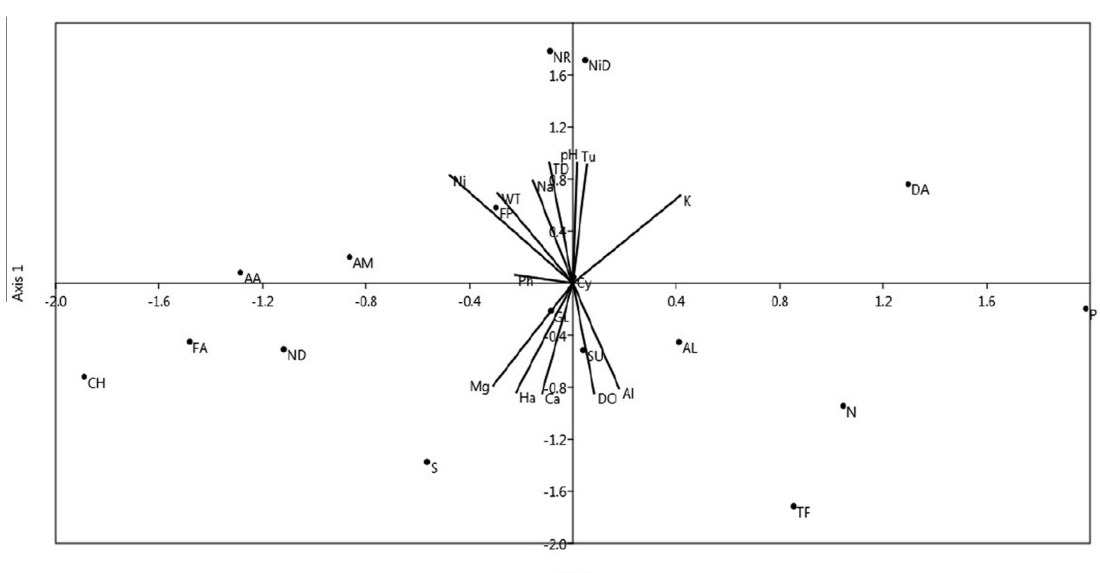

Figure 6 CCA biplot at site 3 between physico-chemical parameters and phytoplankton species (Dominant phytoplankton species: CA: *Cymbella aequalis*, DA: *Diatoma vulgaris*, FP: *Fragilaria pinnata*, FA: *Fragilaria arcus*, GL: *Gomphonema longiceps*, NR: *Navicula radiosa*, ND: *Nitzschia diversa*, NiD: *Nitzschia denticula*, P: *Pinnularia* sp., AA: *Achnanthes afflinis*, AL: *Achnanthes lanceolata*, N: *Nodularia* sp. Cy: *Cyclotella* sp., TF: *Tabellaria fenestris*, SU: *Synedra ulna*, S: *Spirogyra* sp., CH: *Chlorococcum humicola*, AM: *Anabaena ambigua*).

Table 3 Pearson's correlation coefficient between physico-chemical parameters, dominant groups of phytoplankton and phytoplankton density in headwater stream Baldi from November 2011 to October 2012.

	WT	Tu	TDS	pH	DO	Alk	Ca	Har	Mg	Ni	Phos	Na	K	Ba	Chl	Cy	TDP
WT	1.000																
Tu	0.769	1.000															
TDS	0.705	**0.986**	1.000														
pH	0.837	**0.933**	**0.897**	1.000													
DO	−0.835	**−0.962**	**−0.947**	**−0.954**	1.000												
Al	0.840	**0.934**	**0.916**	**0.969**	−0.977	1.000											
Ca	−0.763	**−0.973**	**−0.949**	**−0.953**	0.958	−0.959	1.000										
Har	−0.693	**−0.968**	**−0.946**	−0.873	**0.929**	−0.876	**0.961**	1.000									
Mg	−0.594	−0.907	−0.889	−0.757	0.850	−0.757	0.873	**0.974**	1.000								
Ni	0.827	0.835	0.829	0.887	**−0.912**	0.875	−0.815	−0.768	−0.685	1.000							
Ph	0.825	0.909	0.893	**0.936**	**−0.971**	**0.987**	**−0.928**	−0.860	−0.755	0.864	1.000						
Na	−0.636	−0.531	−0.513	−0.726	0.666	−0.662	0.579	0.479	0.370	−0.842	−0.629	1.000					
K	0.799	0.866	0.806	0.765	−0.832	0.803	−0.843	−0.871	−0.843	0.618	0.811	−0.254	1.000				
Ba	−0.866	−0.911	−0.873	**−0.943**	**0.961**	**−0.977**	**0.934**	0.864	0.756	−0.819	**−0.967**	0.611	−0.856	1.000			
Chl	−0.857	−0.923	−0.882	**−0.942**	**0.962**	**−0.972**	**0.939**	0.883	0.785	−0.810	**−0.965**	0.595	−0.874	0.996	1.000		
Cy	−0.800	−0.892	−0.851	−0.900	0.930	**−0.940**	**0.911**	0.869	0.785	−0.736	−0.945	0.531	−0.872	0.978	0.988	1.000	
TDP	−0.860	−0.914	−0.876	−0.941	0.961	**−0.975**	**0.935**	0.871	0.768	−0.811	−0.966	0.602	−0.864	0.999	0.999	0.984	1.000

Correlation significant at $p < 0.05$.
Abbreviations: WT: Water temperature, Tu: Turbidity, TDS: Total dissolved solids, pH, DO: Dissolved oxygen, Al: Alkalinity, Ca: Calcium, Mg: Magnesium, Ha: Hardness, Ni: Nitrates, Ph: Phosphates, Na: Sodium, K: Potassium, Ba: Bacillariophyceae, Chl: Chlorophyceae, Cy: Cyanophyceae, TDP: Total phytoplankton density (annual average).
Bold significant values show high correlation.

stream. Similar findings were reported from Tyne River, South Africa (Sibanda et al., 2013). Factors controlling phytoplanktonic growth include light, water temperature, water current, substrate and water chemistry (Hynes, 1971; Whitton, 1975; Biggs, 1996). Density of Bacillariophyceae has negative correlation with water temperature ($r = -0.866$, $p < 0.05$). Similar relationship was also reported in Tungabhadra River (Suresh et al., 2013). Growth of phytoplankton composition is governed by the temperature (Rajkumar et al., 2009; Singh, 1960). Turbidity is the detrimental factor which limits the growth of phytoplankton (Hynes, 1971; Sharma et al., 2007). Turbidity has negative correlation with density of Bacillariophyceae ($r = -0.911$, $p < 0.05$), Chlorophyceae ($r = -0.923$, $p < 0.05$) and Cyanophyceae ($r = -0.892$, $p < 0.05$) during the present study. Nitrates have negative correlation with Chlorophyceae. ($r = -0.810$, $p < 0.05$) and Bacillariophyceae ($r = -0.819$, $p < 0.05$). Phosphates also have negative correlation with the density of Chlorophyceae ($r = -0.965$, $p < 0.05$) and Bacillariophyceae ($r = -0.967$, $p < 0.05$). Similar correlation was also reported from Tungabhadra River (Suresh et al., 2013). The abundance and composition of phytoplankton communities are controlled by available nutrients and light (Reynolds, 2006; Altman and Paerl, 2012; Basu and Pick, 1997).

Conclusion

This paper summarizes the monthly and seasonal variations of physico-chemical parameters and their influences on phytoplankton community of headwater stream Baldi with an exploration statistical data output. Upper stretch of head water stream was less polluted with high diversity of phytoplankton. However, the S_2 (middle stretch) was influenced by maximum disturbances reflected in terms of high values of TDS, turbidity and nutrients (nitrates and phosphates), low DO concentration and minimum density of phytoplankton. A considerable recovery in the water quality and density of phytoplankton in lower stretch (S_3) has been recorded. The overall study provides a base line data on the prevailing condition of the of headwater ecosystem of the Baldi stream.

Conflict of interest

We declare that we have no conflict of interest.

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